Abstract

Fossil traces (mainly) provide evidence for the symmetrical break-up of a sulfur and other isomers that could be indicative of primordial two-core nuclei.

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23.70.+j	(Heavy-particle decay)
21.60.Gx	(Cluster models)
27.30.+t	($20 \leq A \leq 38$)

Minute colored spherules that owe their existence to a centrally located inclusion can be found in many transparent minerals and have been studied particularly in mica. The two-dimensional manifestation of such structures seen in the thin medial plane shows up as one or more rings surrounding the inclusion. These rings are the well-known pleochroic, or radioactive, halos. They constitute one of the oldest subjects in nuclear science. Early on, it was suggested that a halo radius corresponds to the range of α-particles emitted from the inclusion, an idea that has since been quantitatively verified for the common U and Th family halos. Many representative microphotographs and the most recent detailed discussion of the phenomena can be found in Ref.[1]. But if the origin of some halos is well-understood, it is important from a research point of view to recall that there are still others for which no explanation has ever been offered. Those we will be concerned with here are the dwarf halos[2][3][1][4] which have long been relegated to the status of enigmatic (the word often used) curiosities. They are so named because the largest of their 1.5 - 11 μm radii[4] is shorter than that of $\approx$ 13 μm produced by the 4.0 MeV α-particles of ^{232}Th. The basic reason for their being a lack of any explanation , and one that has existed to the present day, lies in the dilemma of reconciling a sufficient low-energy particle flux with both mass systematics and Geiger-Nuttall. Or what is much the equivalent, the requisite low energy α-particle (or other) emissions have not been observed. The 2.23 MeV α-particles from ^{147}Sm would produce a radius of $\approx 6\ \mu$m, but the specific activity of the isotope is probably an order of magnitude too low to form a halo. The single rings which are one distinguishing characteristic of the dwarf halos have provided no help in proposing a decay. This feature has always precluded localizing a decay sequence or a mass partition. As far as can be determined, notably from etch profiles, the dwarf halos were formed by charged particles originating from the central inclusion. They represent well-documented and unique data on anomalously ranged particles.

Kinematically, single rings can arise only from a very asymmetrical break-up which leaves a heavy low-range recoil, or a break-up with a symmetrical charge and mass partition. Of course, the rings are "single" to within some resolution, dictated at least by the size of the inclusion and the statistics of the stopping process. The fatal contradiction associated with an asymmetrical break-up (α-decay for example) has been alluded to above. This leaves the symmetrical break-up as the essentially incontrovertible alternative. By considering the shortest halo radius, one can propose a rather more specific scenario. If we assume that the mutual push given to the decay products is Coulombian, and by analogy to long period α-decay that the disintegration takes place at an energy of $\approx 20\%$ of the barrier, we find (Table 1) each partner in a symmetrical break-up would have Z ≈ 8. Another distinguishing feature of the dwarf halos, the highly exposed nature of the halo disks, is consistent with the notion of heavy ion emissions from the central inclusion.

The next and more far-reaching implication that follows concerns the nature of the precursors. All known nuclides except ^{8}Be and certain of the heaviest synthetic elements are stable against any more or less symmetrical decay either because the reaction is endothermic or because of a probability approaching zero[5]. It then appears necessary that a predominantly symmetrical break-up mode would have to arise from a precursor that had conserved its two-core structure. Such entities should be bound. Since the lightest well-developed core is ^{16}O (Z = 8), we might expect a simple two-body decay to be associated with sulfur (Z = 16). Reports of a short-range radioactivity associated with sulfides would be consistent with the present idea.

Extensive prewar and wartime work (partly summarized in the introduction of Ref.[6]) settled on sulfide minerals and particularly the sulfide slag as the richest natural source of a weak unidentified short-range radioactivity. Zincblende was a starting material often used. However, it is difficult to know how much confidence to accord the various reports because the work was never brought to a successful conclusion. Indeed, if the idea in the preceding paragraph is confirmed, it could not have been without a singular turn of mind. Considerations on where to look for low-energy particles had for result that pure elements with Z $\leq$ 42 were not assayed for radioactivity because the mass differences for α-particle decay were assumed to render them inactive. The attending corollary was that when definitive experiments were attempted, the wrong energy group was sought for in the wrong place. The main interest here in these early findings is that an unrecognized radioactivity might still persist in sulfur, although the possibility is not a condition for the interpretation we place on dwarf halo formation.

The energy of oxygen ions deduced from the halo radius would be $1.60^{+0.48}_{-0.42}$ MeV[7]. Possibly relevant work[8] has reported tracks of 3 or 4 μm in nuclear emulsion loaded with solutions of certain iron-containing ores. If these tracks represent back-to-back oxygen ions from associated sulfur, the inferred kinetic energy of each would be about 1.0 - 1.7 MeV. Still other work[9] employing an ionization chamber showed a group at 1.43 MeV associated with technical zinc and with sulfide precipitates from it. These results, by three different methods, provided they correspond to the same decay, show remarkable agreement for completely independent determinations, each near a limit of being measurable. For ions too far removed from oxygen, the agreement disappears. The observation of a supernova remnant enriched in oxygen and sulfur by nuclear processes[10] might be significant in the present context. It can be seen from photomicrographs [11] of larger relatively abundant etched dwarf halos (radius $\approx 4.5\ \mu$m) that their etch profiles resemble the damage profiles [7] for Z = 20 or 28 heavy ions (as expected for this radius on the present model) and not that of α-particles whose major damage lies in a narrower zone near the halo perimeter. A WKB estimation with a simple Coulomb barrier would prefer an energy of $\approx$ 1 MeV for oxygen ions from the break-up of a primordial sulfur isomer. Nevertheless, an energy around this value presupposes a barrier penetration process.

Since the concentration of these precursors in any terrestrial sample must be very low, it might be useful to recall at this point that the (Precambrian) mica in which the dwarf halos have been found is capable of integrating count rates far below anything detectable in the laboratory. One can estimate from the $\sim 10^8$ - 10^9 α-particles needed to form a U halo[1], relative stopping powers[7], and inverse squares of radii that $\sim 10^5$ - 10^6 oxygen ion producing decays could form the smallest dwarf halo.

A static nuclear molecular model that could account for such a result has been proposed[12], but calculations for two ^{16}O cores bound together by neutrons have not been performed. The energetics of the structure and decay summarized by the equation $2 \times {}^{16}\mathrm{O} + 2\mathrm{n} - \mathrm{E}_B + \mathrm{E}_C = {}^{16}\mathrm{O}\ (\mathrm{g.s.}) + {}^{18}\mathrm{O}\ (\mathrm{g.s.}) +$ kinetic energy, where E_B is the binding energy of the two neutrons in the composite potential well and E_C the increase in Coulomb energy due to the proximity of the two charged cores, could be about right[13]. For comparison, the Q-value for the reaction ^{34}S (g.s.) = ^{16}O (g.s.) + ^{18}O (g.s.), the most energetically favorable nearly symmetrical break-up, is − 24.4 MeV[14]. One general theoretical result[12], consistent with the present thesis, is that the exchange necessary for nuclear molecular binding is important only between identical cores.

The deductions based on the shortest reported halo radius suggest possibly the least ambiguous case of a symmetrical break-up, that of a sulfur isomer. But the range of radii allows us to think that analogous long-lived heavier systems exist. It should be clear that such radioactivities are not simply new examples of superdeformation or usual cluster decay (which for several reasons, including α to cluster branching ratios and cluster ranges, one cannot propose an adequate decay [5]). A two-core isomer represents a fundamentally different idea of nuclear matter because of the necessary discontinuity in the proton cloud. Such a basis would allow one, conceptually at the moment, to tack on an additional subunit. Arguments for this eventuality can be constructed from existing unexplained data in much the same manner as has been done above for two-center species.

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Table 1: Energies E of several ions having a range R = 1.5 ± 0.3 μm [a] in mica, Coulomb barriers E_C for two like ions, and Q/E_C which is a determining quantity in a barrier penetration.

Ion	[b] E or Q/2 (MeV) (for R = 1.2 - 1.5 - 1.8 μm)	[c] E_C (MeV)	Q/E_C (%) (for the 3 energies in col.2)
^{4}He	0.33 - 0.43 - 0.54	0.91	72 - 94 - 119
^{12}C	0.96 - 1.29 - 1.66	5.96	32 - 43 - 56
^{14}N	1.15 - 1.54 - 1.98	8.61	27 - 36 - 46
^{16}O	1.18 - 1.60 - 2.08	11.8	20 - 27 - 35
^{19}F	1.15 - 1.56 - 2.04	13.7	17 - 23 - 30
^{20}Ne	1.15 - 1.57 - 2.07	16.6	14 - 19 - 25
^{24}Mg	1.08 - 1.37 - 1.80	24.0	9 - 11 - 15
^{32}S	1.72 - 2.31 - 3.00	38.7	9 - 12 - 16
^{40}Ca	2.05 - 2.71 - 3.37	60.2	7 - 9 - 11

a) Ref.[4] gives an approximate measuring uncertainty of 0.25 μm for larger dwarf halo radii.

b) Calculated from Ref.[7] for biotite with the density set at 2.95 g/cm^3 to reproduce known ranges of α-particles (Ref.[1]) in this material.

c) $E_C = Z^2e^2/(2\ r_o\ A^{1/3})$ with r_o diminishing from 2.0 fm for He to 1.4 fm for Ca (Ref.[15]).